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# Use of the Er:YAG Laser for Improved Plating in Maxillofacial Surgery: Comparison of Bone Healing in Laser and Drill Osteotomies

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***Background and Objective:*** Surgical reconstruction of bony defects in the maxillofacial region involves fixation of bony fragments with mini and micro plates. Bone stabilization during hole drilling is often challenging due to the need to apply pressure when using a conventional mechanical Hall drill. In addition, fragmentation of the fragile bones may occur and complicate the reconstruction. The pulsed Er:YAG laser offers an attractive alternative drilling modality because it does not require physical contact with the bone in order to drill holes, cuts bone with minimal thermal damage, and allows precise control of bone cutting. The objective of this study was to investigate the pulsed Er:YAG laser as an alternative to the mechanical bur by comparing bone healing using both modalities.

***Study Design/Materials and Methods:*** Bone healing in an inferior border defect of the rat mandible was examined using either an Er:YAG laser or a mechanical bur for drilling. The healing of osteotomies in facial bones and of screw holes for plate stabilization of free bone fragments was studied.

***Results:*** All defects healed by 4 weeks postoperatively. Histologic evaluation demonstrated no difference in the amount of newly formed woven bone at the osteotomy site or screw holes made by either the laser or the drill. The extent of thermal damage at the osteotomy sites was comparable in laser and mechanically cut bone fragments.

***Conclusions:*** On the basis of this study we suggest that the Er:YAG laser can be used clinically in thin, fragile bones in the maxillofacial region. 

Key words: Er:YAG laser, facial bones, laser osteotomy, healing

## INTRODUCTION

The stabilization of bone fragments in the maxillofacial region is often very difficult and challenging. Fixation of these fragments is usually done by screw-stabilized mini or micro plates. Because of the fragile nature of these thin bones, fractures may occur when a conventional mechanical drill is used. We therefore were interested in determining whether the use of a laser to cut and drill holes in this type of bone could be clinically advantageous in comparison with the traditional method of using a Hall drill. Because there is no need to exert pressure on the bone, lasers may be superior to mechanical drilling.

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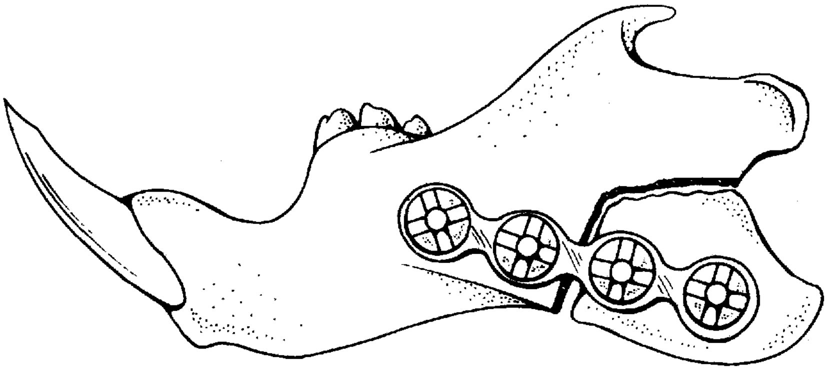

Fig. 1. Line drawing of the rat mandible inferior border defect that was created by horizontal and vertical osteotomies in the posterior body. Fixation of the free segment was achieved with a 4-hole micro plate.

The use of lasers for cutting and drilling hard tissues has been investigated for application to a wide range of dental and endodontic applications [1–5]. However, no studies of the use of lasers for reconstructive procedures in the maxillofacial region exist [6–9]. A number of studies have demonstrated that the Er:YAG laser cuts bone precisely, with minimal thermal damage of 10–15 μm [10–14]. The application of the Er:YAG laser to maxillofacial surgery appears attractive, since only a small amount of material needs to be removed. The low average power laser provides holes comparable to those obtained using mechanical drills, and its use results in minimal thermal damage. In addition, the fact that it removes a fixed amount of material per pulse makes precise control of cutting depth possible. Since a previous study using a rabbit tibia model reported delayed healing of laser osteotomies compared with conventional saw osteotomies [15], application of laser cutting and drilling to facial bones in clinical practice requires evaluation of healing at that site.

We therefore compared healing of Er:YAG laser and mechanical osteotomies in an animal model simulating the structure of the bones in the infraorbital and sinus region in humans. Osteointegration of screws in holes made by both the Er:YAG laser and the mechanical Hall drill was also compared.

## MATERIALS AND METHODS

Ten adult male Sprague Dawley rats (450–550 g) obtained from Taconic Laboratories (Germantown, NY) were used. As shown in Figure 1, an inferior border defect was created bilaterally in the mandible. After the vertical osteotomy was made, one hole was drilled in the anterior portion of the mandible. A four-hole micro plate (straight Titanium 4-hole-Ultra-Micro Plate, Walter Lorenz Surgical Instruments) was loosely attached and used as a template for drilling three additional holes. Fixation of the plate was achieved with the use of two mini screws (Walter Lorenz Surgical Instruments) in the anterior two holes (1.5 × 3.5 mm) and two mini screws in the posterior two holes of the mandible (1.5 × 2.5 mm). After securing the plate, a horizontal osteotomy was made (Fig. 1). A 28 g needle was passed along the length of the horizontal osteotomy site to ascertain that the cut was complete. Both sides were operated under sterile conditions with copious saline irrigation and suction to avoid pooling of water and blood, which affects ablation efficiency.

On the right side, a twist drill (1.0 × 48 mm, 5 mm stop, with notch, Walter Lorenz Surgical Instruments) was used for making the screw holes. The osteotomies were made with a cross-cut fissure bur (Fissure, HP, 1¾ inch, 44 mm, 700, Walter Lorenz Surgical Instruments).

On the left side, an Er:YAG laser (Schwartz Electro-Optics, Concord, MA) optically connected to a Zeiss OPMI 1 F/C operating microscope by an articulated arm was used for cutting and drilling. It produced a 100–200 μs pulse train consisting of 1-μs long pulses. The energy delivered per pulse was measured using a Gentec ED-200 pyroelectric joulemeter and oscilloscope. A collinear helium-neon visible laser beam was used for aiming. The beam diameter at the tissue was 330 μm, as defined by the $e^{-2}$ intensity points. Both lasers were aimed by way of a micromanipulator, similar to those used with clinical $CO_2$ laser systems (Laser Mechanisms, Southfield, MI). Experiments were typically performed using a 53 mJ pulse,

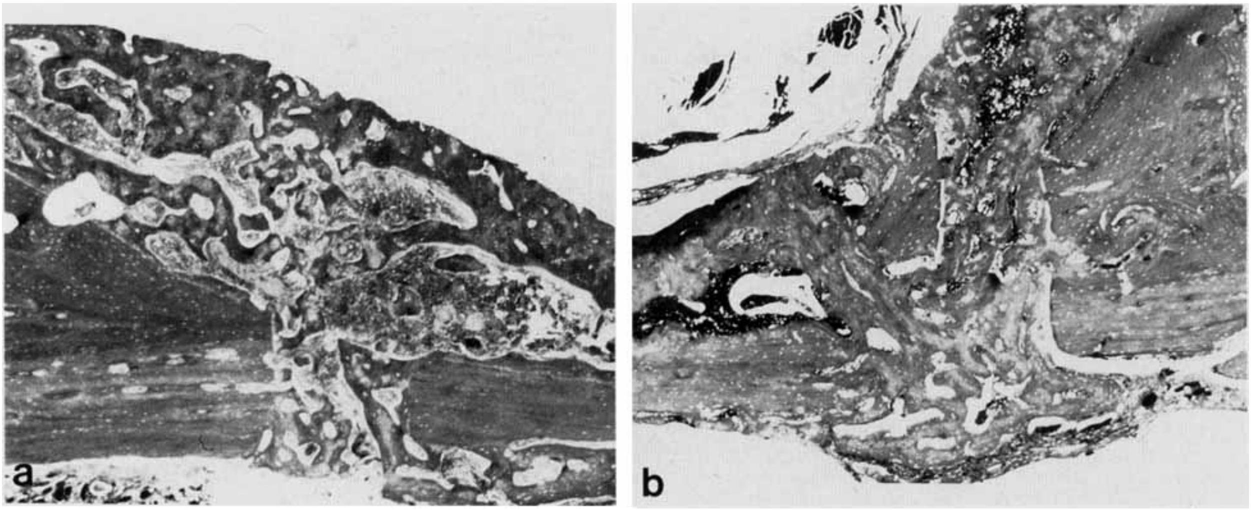


Fig. 2. Photomicrograph of longitudinal sections (2.5×) through the vertical osteotomy junction site. The osteotomy was performed with the Er:YAG laser (**a**) and a cross-cut fissure bur (**b**). Both sections show a similar extent of endochondral bridging callus at the osteotomy site, with periosteal bone formation originating from both the fragment and the mandible.

with three to five pulses required to drill through the mandible. The fluence per pulse was typically 60 J/cm$^2$. Instead of using a 1 mm spot size for drilling screw holes, holes were further enlarged to fit 1 mm diameter screws by slight translation of the beam around the circumference of the hole, which required an additional 15–20 pulses. This less time-consuming technique was chosen because the ablation efficiency was noted to be drastically reduced with increasing spot size due to continuous pooling of blood.

Animals were followed postoperatively for 4 weeks. After sacrifice, bone specimens were retrieved, fixed in 10% buffered formalin, decalcified in EDTA, and paraffin embedded. Serial longitudinal sections (5 μm) of the posterior body of the mandible were cut and stained with hematoxylin and eosin.

Slides were examined for the amount and location of bone resorption and new bone formation. The amount of thermally damaged bone was indirectly assessed by the amount of remodeling of nonvital or necrotic bone and by histomorphometric measurements of the distance from the osteotomy site to the presence of viable bone in both the free fragment and the body of the mandible. Histologic evaluation of the healing at the vertical osteosynthesis site was used as an indicator of the biological reaction of the bony tissue to laser or mechanical cutting.

## RESULTS

Gross visual examination of the bone specimens after retrieval revealed a bony union at the osteosynthesis site in 18 of the 20 hemimandibles. One laser-cut and one drill-cut specimen had no bony union. In these mandibles, the free bone fragment failed to heal at the horizontal junction site because of insufficient fixation and loosening of the micro plate. These bone specimens were excluded from further study.

Histologic evaluation of the remaining bone specimens revealed endochondral callus formation at the junction site. Extensive periosteal bone formation originating both from the free bone fragment and the mandible was evident in all bone specimens. This was a consistent finding in both laser and mechanically cut bone specimens. Figure 2a and 2b shows representative sections with comparable amounts of newly formed woven bone in both laser and drill osteotomy sites.

The extent of thermally damaged nonvital bone, measured histomorphometrically by the distance from the osteotomy site to the presence of vital osteocytes, ranged from 25 to 100 μm in both laser and mechanically cut bone specimens. No necrotic bone was noted in any specimen. Minimal remodeling of the mandible on both sides of the osteotomy site demonstrated resorption and

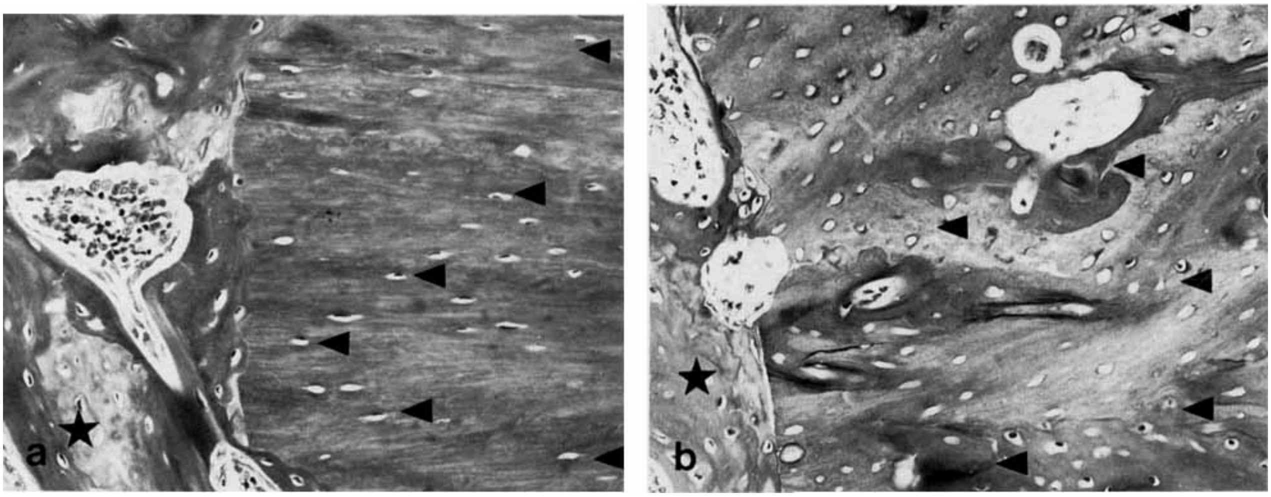


Fig. 3. Photomicrograph of longitudinal sections (10×) taken at the vertical junction site showing new woven bone and callus formation (★) and the zone of nonvital thermally damaged bone. The thermal damage zone is marked with arrowheads at the interface between viable and nonvital bone. The osteotomy was performed with the Er:YAG laser (**a**) and a cross-cut bur (**b**). The zone of damaged tissue extends approximately 25–50 μm from the osteotomy cut on each side.

replacement by woven bone, indicative of normal fracture healing (Fig. 3a,b). Histologic evaluation of both laser and mechanically drilled screw holes demonstrated results similar to those described earlier. Osteointegration of the screws in the mandible was observed.

## DISCUSSION

This study demonstrated comparable healing using either an Er:YAG laser or a conventional mechanical bur in the rat inferior border defect model. The precise cutting of bone by the Er:YAG laser has been discussed in several publications [11–13,16]. It results from both the short optical penetration depth of 2.94 μm laser radiation in bone and from the fact that this pulsed laser removes bone by explosive vaporization. The absorption coefficient of liquid water at 2.94 μm is $1.3 \times 10^4$ $cm^{-1}$ [17]. This corresponds to an optical penetration depth (the distance at which the light intensity is reduced to 1/e or 0.37 of its value at the surface) of approximately 0.8 μm. Since bone has a water content that can vary from 10% to 25%, the actual contribution of water to the infrared absorption of bone will result in an optical absorption coefficient of $1.3–5.2 \times 10^3$ $cm^{-1}$. Thus the penetration depth may be as high as 8 μm. The absorption of other bone components, such as collagen, may decrease the penetration depth further. It should be noted, however, that the absorption spectrum of water can shift with heating, giving rise to ablation depths different from those expected using a fixed absorption coefficient [18].

In contrast, continuous wave (cw) surgical lasers such as the $CO_2$ laser remove bone by heating it to the point of vaporization and pyrolysis, resulting in extensive char formation and delayed healing [19–21]. These cw lasers are inappropriate for the precise cutting and hole drilling desired in maxillofacial surgery.

Other pulsed infrared lasers have been applied to bone cutting [16,22,23]. The use of a Q-switched Nd:YAG laser producing a 10 nsec pulse resulted in thermal damage zones of 10–15 μm at fluences between 8.1 and 27 J/$cm^2$, corresponding to irradiances of the order of $10^9$ W/$cm^2$ [16]; this system may also be applicable to cutting and drilling of facial bones. It should be noted, however, that the 1.06 μm radiation of this laser is very weakly absorbed by water and that cutting is due to the plasma generated by the focused laser beam [16].

The animal model used in this study was particularly suitable for studying the biological effect of Er:YAG laser ablation on the healing of facial bones because the rat mandible is only 1 mm or less thick in the posterior body region and therefore serves as a model for the bones in the

infraorbital and sinus region in humans. Similar models have been previously described in the rabbit and dog [24,25]. The use of the Er:YAG laser in this model was technically advantageous because of the ease of drilling holes and attachment of the fragment to the plate. Once the plate is fixed to the fragment, it can be more easily moved into position, and the holes for the attachment of the plate to the corresponding bone can be drilled. This situation parallels a common clinical problem.

As there was no difference in the healing at the osteotomy sites, nor in fixation of the free fragment with the two cutting modalities, we suggest that the Er:YAG laser be considered an alternative to the conventional Hall drill when plating of thin bones, such as those in the infraorbital and sinus region, is necessary. Since stabilizing the fragments can be very difficult in midface fractures, the ability to make screw holes without having to stabilize the bone fragment is useful and eliminates the potential of the bur fracturing the bone. However, the use of the Er:YAG laser for cutting thicker bone is more time consuming and therefore less clinically advantageous.

Our findings differ from a previous study that reported delayed healing of an osteotomy made by a mid-infrared Er:YAG laser (2.94 μm) [11]. These differences in healing are most likely due to the different animal model used. The soft tissue cuff at the anterior aspect of the tibia is much smaller and less well vascularized and the bone much thicker than tissues in the facial region. This may have affected the healing of the osteotomies in the rabbit tibia model. The pulsed Er:YAG laser appears to be an effective and precise bone ablator and is useful when control of depth, as in the reconstruction of midface fractures in the infraorbital and sinus region, is required.

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